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RESEARCH PAPER

Particulate Matter Emissions From Domestic Biomass Burning in a Rural Tribal Location in the Lower Himalayas in India: Concern Over Climate Change

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Abstract Estimates are made of mass of particulate matter (PM) in air containing black carbon (BC), due to use of biomass cooking energy in the forest-dependent tribal community of Jaunsar, Uttrakhand, based on data collected from a sample of households. BC acts as facilitator for climate modification. Kitchen-structure-related issues, biomass burning schedules and emission of smoke during the cooking process, which ultimately determine the exposure levels of family members, were investigated. Residents' houses are in general made of wood with small kitchens with poor ventilation. More than 90% of households use traditional chulhas and burn unseasoned fuelwood. Chulhas typically burn for about 5 h and cook 2–3 meals/day. High smoke concentration was observed during the start of burning in chulhas, for from 3 to 30 min depending upon the quality of fuel. The total annual PM emission of the 14,399 Jaunsar households as result of fuelwood combustion was estimated at 0.67 Mt with annual BC emission of 0.33 Mt. This has serious implications for climate change as well as health of the rural population.

Keywords Black carbon · Carbonaceous particles · GHG · Fuelwood cooking

Introduction

Worldwide, approximately 50% of all households and 90% of rural households utilize solid fuels (biomass and coal) for cooking or heating (Bruce et al. 2000).

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Recent studies have indicated that with increasing population there is a substantial increase in consumption of biofuel for cooking energy in third world countries. Recent evidence suggests that 25% of the global energy requirement is obtained from biofuels (Koppmann et al. 2005), compared with about 15% in the 1980s (Hall 1991).

Energy use in India—with 80% of rural population who account for 40% of national energy consumption—is characterized by high reliance on traditional fuels (particularly fuelwood). NSSO (2002) found that 75% of all rural communities utilize fuelwood as the main source of cooking fuel. In rural India, the primary energy use of biomass consumption was 54% from wood, 15% from crop residues and 21% in the form of dung-cakes (FAO 1999). Bhattacharya and Nanda (1992) reported that national fuelwood demand ranged from 96 to 157 million tons (Mt) annually, with fuelwood demand of 80–128 Mt for rural areas. More recently, Aggarwal et al. (2009) reported an annual rural demand of 228 Mt. The annual consumption of dry wood in various parts of the Himalayas is reported to be much higher than in other parts of India due to the prolonged cold period (Singh 1989; Metz 1990; Singh et al. 2010).

Fuelwood use leads to the environmental problems of deforestation and emissions to the atmosphere of particulate matter (PM) as well as greenhouse gases, notably CO_2. Emissions from biomass burning in indoor environments have adverse impacts on human health, with high vulnerability of women and children (Smith 2006; Pandey 2011). Huboyo et al. (2009) argued that poor ventilation in rural housing was the main cause of indoor air pollution (IAP), which leads to respiratory illness, cardiovascular disease and adverse pregnancy outcomes (Bruce et al. 2000; Smith et al. 2000; Laxmi et al. 2003; Smith 2005).

Biomass burning can alter the regional climatic conditions in particular and global conditions in general (Koppmann et al. 2005; Streets 2006; Ramanathan and Carmichael 2008). There is a huge gap in understanding the impact of domestic combustion emissions on climate change, although the effect of outdoor burning has been explored extensively. There have been few studies which correlated gaseous emissions from domestic fires with changes in atmospheric processes (Koppmann et al. 2005), and these studies did not take into account the emissions of particulate matter (PM) containing black carbon (BC). PM, the fine carbonaceous particles, contains a substantial proportion of (BC) (Huboyo et al. 2009). A few studies have reported the PM concentrations in the air, in households utilizing solid fuels, including Bruce et al. (2000), Balakrishnan et al. (2004) and He et al. (2005). These authors concluded that there is a correlation between the concentrations of respirable particulates with fuel type, kitchen type and fuel quantity.

BC, consisting of highly energy-absorbing particles, is a newly recognized climate modifier formed through the incomplete combustion of fossil fuels, biofuel and biomass and is emitted in both anthropogenic and naturally occurring soot. Residential burning of coal and biomass and commercial burning of diesel are the main sources of BC emissions (Cooke et al. 1999; Streets et al. 2001). BC has a global warming effect, including on snow, and also plays an important role in

regional warming because it contributes to haze and reduces insolation.[1] BC stays in the atmosphere for only several days to weeks, hence the climate change effect is short relative to carbon dioxide. Therefore, reducing BC emissions is potentially a rapid means of slowing climate change (Wikepedia 2011).

Global annual emissions of BC for the year 1996 accounted for 8 Mt, with about 20% from biofuels, 40% from fossil fuels and 40% from open biomass burning (Bond et al. 2004). Menon et al. (2002) reported that BC emissions are particularly high in India and China. BC in indoor environments is largely due to cooking with biofuels including wood, dung and crop residue (Ramanathan and Carmichael 2008). BC also presents a high risk to human health in cooking using firewood (Huboyo et al. 2009), including eye damage (Qiu and Yang 2000).

Most BC particles are less than 1 μm (10^{-6} m) in diameter. Because of their small size, they have long atmospheric residence time, ranging from a few days to several weeks, and may therefore travel hundreds to thousands of kilometers before they fall to earth (Penner et al. 1993). Streets (2006) argued that BC is the second most important contributor to global warming after CO_2, and is not degraded under atmospheric conditions. BC is removed from the atmosphere by rain and snowfall (Penner and Novakov 1996). On a global scale, BC plays a significant role in climate modification (Penner et al. 2001) and also contributes to changes in weather patterns (Menon et al. 2002). However, clear understanding about the BC is lacking and hence real-time observation through empirical studies is needed to improve understanding of the effects of BC inside and outside dwellings using biomass for cooking, as stressed by Brunekreef et al. (2005) and Huboyo et al. (2009). This paper reports estimates of mass of PM using a crude method of aerosol measurement, and provides a preliminary estimate of the potential impact on regional climate change by extrapolation of measurements due to the mixing of PM into the atmosphere to state level. The study is limited to the environmental impact of emissions from combustion, and leaves aside the debate about whether the utilization of fuelwood is carbon neutral.

The Study Area

The spatial focus of the study was Jaunsar of Dehradun district of Uttrakhand state in the lower Himalayas, lying between 30°31′N and 31°3′30″N latitude and 77°45′E and 78°7′20″E longitude. This region is composed of a succession of peculiarly irregular and precipitous mountains and hills, which are broken by numerous streams and nalas (small tributaries), creating a rugged landscape configuration.

The population is sparsely distributed in 357 scattered small nucleated villages. The total of 14,399 households consists of smallholder communities from 18 to 110 families/village with a total population of 114,693 (Government of India 2001). The community depends on agriculture (crop cultivation) and forests (collection of fuelwood, fodder, fruits, seeds) for their livelihoods (Sishaudhia 1993; Pandey 2007). The people of the region, known as Jaunsaries, have in general two-storied wooden houses.

1 Insolation is a measure of solar radiation energy received on a given surface area in a given time.

Research Method

A questionnaire was developed to investigate the climate change contribution of indoor cooking including other parameters such as socio-economic characteristics of each household, fuelwood consumption patterns, cooking behaviour of households, kitchen structure, and exposure to hazardous pollutants created from fuelwood burning in each household. The questionnaire was tested on 10 households, and some modifications made in respect of quantification of chulha burning time. Interviews were conducted in 48 randomly selected households in nine randomly selected villages (3–9 households/village) of the study area, between June and September 2008.

Ideally, BC emissions are measured by bulky instruments installed near the location where combustion takes place. However, the non-availability of portable instruments, intensive labour involved in the installation of large instruments and unreliable power supply in villages were crucial constraints on the measurement of particulates emitted as a result of incomplete fuelwood burning. To overcome these constraints, expert suggestions were sought from scientists of the Forest Research Institute, Dehradun. On their advice, it was decided to use a crude method to measure the PM through the installation of desiccated Whatman filter paper, placed 1–1.5 m above emission sources. Filter paper has previously been used for measuring PM emission from fuelwood burning in kitchens by Malgwi (2002) and for estimation of PM in blasting dust of open cut coal mines by Roy et al. (2011).

PM measurements were made at only 20 of the sample households who agreed to this component of the study. Sheets of Whatman filter paper of 24.13 by 33.02 cm were installed on the roof openings situated above the chulhas in the kitchens; these were able to capture most of the PM emitted. Before installation, the filter paper was weighed digitally, and was packed in polythene to avoid exposure to moisture (which would increase the weight of the paper). The filter paper covered the roof opening of the kitchen and was situated above the mouth of chulha for a period of 1 h from the commencement of combustion. At the end of the testing period the paper was removed and repacked in polythene bags. In the lab, the filter was desiccated and weighed and the difference in weight after and before exposure was taken as the weight of PM emitted during the period of combustion.

Results

The region has a large area under forests; however, due to high population pressure, rapid forest degradation has taken place. The families in sample households in Jaunsar were found to be, in general, large in size (a mean of 9 members) with low education (only 43% completed primary schooling). Most respondents were found to be farmers. They collect substantial quantities of forest resources including fodder, fuelwood, tubers and fruit to utilize for their own requirements. Household members must travel long distances and spend considerable time in fuelwood collection due to forest degradation. They have high dependency on fuelwood as the primary source of cooking fuel (Table 1).

Table 1 Descriptive statistics of kitchen and cooking parameters

Parameter	Mean ± SE	Minimum	Maximum
Fuelwood collected at a time (kg)	28.26 ± 1.81	6	80
Cooking frequency/day (no. of meals)	2.37 ± 0.09	1	3
Chulha burning in morning (h)	1.82 ± 0.16	1	5
Chulha burning in midday (h)	0.79 ± 0.15	0	3
Chulha burning in evening (h)	2.37 ± 0.14	1	7
Time for smoke emission morning (min)	12.02 ± 0.98	3	30
Time for smoke emission evening (min)	11.91 ± 0.91	3	30
Time for smoke emission midday (min)	4.46 ± 1.00	0	25
Number of pots in a chulha	2.78 ± 0.09	1	5

The kitchen structures are an important determinant for pollution emissions. Respondents mostly had houses made from wood harvested during the clearing of the local forest; however, some had pucca (made of brick) houses. Locations of kitchens within houses depended on the size of the house and social status of the family. Generally, kitchens were constructed out of wood. Most of the kitchens were small (less than about 6 m^2); 50% had no ventilation outlets, a further 20% had a small window for ventilation, and 15% had an inbuilt chimney. Only 15% of the sample kitchens were located outdoors, where ventilation was assured. Households cooked 2–3 meals/day. More than 90% of the sampled households (45) were found to use traditional chulhas and to burn unseasoned (poorly dried) fuelwood. The period of concentrated smoke emissions and overall burning time for chulhas depended on the family size and the fuelwood characteristics (mainly the extent of seasoning; Table 1). High smoke concentration was observed after initial ignition of the chulhas, for a period of 3–30 min depending upon the fuelwood quality. These findings clearly reflect the poor kitchen characteristic and therefore restricted flow of emitted gases.

The mean hourly emission of PM/household was estimated at 0.38 g and the mean daily chulha burning time was approximately 4.98 h (Table 1). The survey households had 100% reliance on fuelwood for household energy (as also reported by Panday 2007).

Assuming particulate emissions from domestic biomass combustion contain two-thirds of the bulk carbonaceous aerosols (as reported by Gustafsson et al. 2009), the average emission of carbonaceous particles/year for the Jaunsar can be estimated as:

$$\begin{aligned}&\text{Annual carbonaceous mass from the Jaunsar}\\&\quad = (\text{mean hourly emission of PM/household} \times 0.67)\\&\quad \times \text{mean chulha burning time} \times \text{no. of days in a year}\\&\quad \times \text{total number of households in the region}\\&\quad = 0.38 \times 0.67 \times 4.98 \times 365 \times 14399\\&\quad = 6.67\,\text{metric ton}\end{aligned}$$

This quantity of PM is being generated annually from an area of 1,002 km^2 (Pant and Samal 1998) containing 14,399 households.

The carbonaceous mass released during biomass combustion is characterized by a high content of BC, of generally more than 50% (Gustafsson et al. 2009), and as high as 80% (Novakov et al. 1974). Assuming a 50% share of BC in the carbonaceous PM emitted due to fuelwood combustion, the total annual emission of BC by the households of the Jaunsar is estimated at 3.33 metric ton.

Discussion

Rural people in India are exposed to smoke from various cooking devices for 3–7 h daily during summer, and more during winter due to heating requirements. While the aggregate emission is small for the study area, nationally and globally the high dependence on fuelwood results in a substantial contribution to climate change. Further, it is to be noted that the radiative forcing of BC is 'as much as 55% of the CO_2 rediative forcing and is larger than the forcing due to the other greenhouse gasses of CH_4, CFCs, N_2O, and tropospheric ozone' (Ramanathan and Carmichael 2008), which makes the role of BC emission important from a climate change perspective. Moreover, due to the short average residence time of BC in the atmosphere, reductions in BC emissions produce almost immediate benefits in terms of reduced radiative forcing with co-benefits to public health.

Climate scientists report that decreasing BC emissions would be a relatively inexpensive means of reducing global warming—especially in the short term. Therefore, reduction BC of emissions of is a key remediation strategy from a climate change perspective. Domestic biomass combustion could be replaced by clean fuels such as biogas, natural gas, LPG or kerosene, or direct solar power. However, in practice this is difficult to achieve because clean fuels are not affordable by the poor.

Cooke et al. (1999) and Streets et al. (2001) reported that the BC emissions are associated with fuel type and combustion technology. Therefore, it would be appropriate to investigate efficient fuel type and combustion technology to identify those with comparatively low BC emissions at local level with the current cooking practices. In this respect, it would be appropriate to educate the upland poor about the environmental benefits of changing their cooking practices. This could include using dried wood for burning and selecting fuelwood species with low pollutant emissions, as well as use of improved cooking stoves that burn fuel more efficiently with reduced emissions of BC and other climate-relevant pollutants.

Ultimately, by better understanding the climate and health effects of BC, the most cost-effective mitigation measures for reduction of BC emission can be identified, which would have important environmental and public health benefits. Therefore, the policy perspectives at local level may to target improved household status both in terms of economy and education, so that these households can appreciate the environmental perspectives of pollutants and modify their cooking practices with the options of switching to alternate fuel given their improved economic status.

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